needed. It should be used with silvicultural and chemical control, all of which need much more research aimed at their integrated use.

References

Elton, C. S. The ecology of invasions by animals and plants. John Wiley & Sons, Inc., New York, 1958.

Taylor, T. H. C. Biological control of insects. Ann. Appl. Biol. *42* (1955).

Milne, A. Theories of natural control of insect populations. Cold Spring Harbor Symposium on Quantitative Biology *22* (1957).

Prebble, M. L. Biological control in forest entomology. Bull. Entomol. Soc. Am. (March 1960).

Biological Control Of Forest Tree Diseases

J. R. Hansbrough

Director, Forest Disease Research, Forest Service, Department of Agriculture

America's forests are one of her greatest renewable natural resources. Unlike mineral resources, forests can be utilized, and then, under good management and with adequate protection, they can be regenerated again and again on the same site. During this cycle, they provide lumber and other products, protect the soil from erosion, contribute to water conservation, offer food and cover for wild and domestic animals, and are an important element in human enjoyment of outdoor recreational activities. Maximum use of forests for the greatest public benefit requires constant vigilance to reduce preventable losses from destructive agencies, of which diseases are currently highest on the list.

The several hundred species of trees comprising American forests are vulnerable to the attack of innumerable diseases. Some are caused by pathogens such as fungi, bacteria, nematodes, viruses, and parasitic flowering plants; others by unfavorable environmental influences such as moisture and temperature extremes, nutritional imbalances, and noxious fumes in the atmosphere. Reduction of disease losses is sought through many and diverse measures: (1) quarantines to exclude dangerous foreign pathogens from this continent, (2) special fungicidal, sanitation, or eradication applications to reduce inoculum or to prevent infection, (3) selection and breeding for genetic host resistance, (4) timely application of beneficial silvicultural practices, and (5) stimulation of biotic factors in the forest environment that prevent infection, retard disease spread and intensification, or increase tree vigor.

Quarantines are the first line of defense. Plants and plant parts capable of introducing known potentially damaging forest pathogens are excluded, and incoming shipments of other plant materials are carefully inspected to insure freedom from disease. Quarantine efficiency is steadily improving through research on all continents to identify and characterize forest pathogens and to keep inspection techniques up to date through a continuing training program.

Special direct disease control measures are seldom employed unless all other methods of reducing losses to a tolerable level have failed. Examples of such measures now in practice are fungicidal seedling sprays and soil fumigation in forest nurseries, destruction of currants and gooseberries (the alternative hosts) to protect white pines from blister rust infections and antibiotic applications to cure those already infected, chemical stump treatments to prevent the establishment of root rot infections in forest soils, and sanitation pruning of western conifers to remove dwarf mistletoe infections.

The development of genetically resistant stock for planting in areas of high disease hazard is one of the most promising approaches to permanent reduction of losses from specific diseases. Outstanding progress has been made in producing white pines resistant to the introduced blister rust fungus, elms resistant to the phloem necrosis virus and the Dutch elm disease, shortleaf pines resistant to the littleleaf disease, longleaf pines resistant to brown spot needle blight, and southern pines resistant to fusiform rust.

Biological control of forest diseases, the major theme of this paper, may be defined in two ways. In the broad sense it includes all biotic measures that favor tree growth and health or are unfavorable to pathogens; in a much more restricted sense, it includes only the action of parasitic or predaceous organisms on the pathogens that cause forest diseases. Each of these concepts will be examined separately, beginning with the application of beneficial silvicultural practices.

Many forest pathogens, including most of those native to this continent, depend upon reduced tree vigor or upon injuries to provide an opportunity for successful attack. Losses from all such diseases may be reduced by applying measures to maintain or increase tree vigor or to prevent injuries. In essence, this amounts to growing the right tree on the right site, providing it with adequate growing room, and protecting it from natural and man-made injuries. Practice of this kind of forest management involves consideration of site selection, species mixtures, stocking, rotation age, stand regeneration, cultural treatments, and prevention of wounds that serve as infection courts for pathogens.

Trees growing on good sites for the species are more vigorous and in general are less susceptible to disease attacks than those on poor sites, indicating the need for better appreciation of the site requirements of important species. For example, research has shown that the littleleaf disease of shortleaf pine occurs only on heavy soils with poor internal drainage, a situation favorable to the causal fungus. This disease may be controlled by converting to other species on high hazard sites, particularly to hardwoods that are known for their soil building capacity.

In most instances, trees growing in mixtures are more vigorous than those in pure stands, indicating the need for more information on the effects of stand composition on disease incidence. A good rule of thumb is to follow nature. If a tree species occurs naturally in mixture with other species, the same mixtures should be encouraged under management. If it occurs naturally in pure stands (*i.e.*, Douglas fir), it may be assumed that disease hazards are not emphasized by stand purity alone.

Trees growing under ideal stocking according to age and size are more vigorous than those in over-dense or wide open stands, indicating the need for research on the relationships between spacing and disease attacks. For example, Hypoxylon canker of aspen is more abundant in open stands and on exposed trees at the edges of stands than in the interior of closed stands. Proper spacing affords some biological control of this disease.

Trees from sapling to physiological maturity are more vigorous than those that are overmature, indicating the need for recognition of the age at which different species reach maturity. In all species that have been studied, the incidence of heart rot is directly related to age. The rotation age should not exceed that age at which heart rot losses become excessive.

Naturally regenerated stands are usually more thrifty than planted ones, presumably for two reasons: they are better suited to the sites and root formation, and distribution in the soil is not adversely affected by planting techniques. If planting must be resorted to, great care should be exercised to assure that the species and the provenance of seed are appropriate for the site. Incidentally, native species are almost universally more vigorous than exotics, indicating the need for caution in establishing tree species in areas or on sites where they do not occur naturally. For example, Scots pine plantations in North America have seldom reached maturity without excessive pest attacks, often resulting in complete loss. Even more striking is the fact that Tympanis canker of red pine occurs almost entirely in plantations south of the natural range of the species; it has never been observed in naturally regenerated stands and is of no consequence in plantations in areas where red pine occurs naturally.

Cultural treatments such as thinning to optimium spacing, pruning lower or diseased branches, reducing sprout clump, harvesting without site degradation, or even correcting nutritional imbalances by artificial fertilization can be carried out so as to reduce disease incidence or to prevent new infections. All cultural measures should be considered in relation to disease occurrence and should be properly timed for maximum utility in disease suppression. For example, dwarf mistletoe in western conifers can be controlled by sanitation to remove infected trees or parts of trees, thereby preventing infection of understory reproduction, which is the nucleus of the next generation. In all cultural operations, diseased trees should be removed to leave the residual stand in the best possible condition.

Uninjured trees are more vigorous than those that have had to undergo or withstand any deteriorating or injurious influence. Fire and logging scars are the most frequent kinds of wounds that provide entry for heart rot fungi and other pathogens. Fire prevention and careful logging to avoid injuries to residual trees are effective means of reducing disease losses.

It is obvious that many biological factors contribute to disease incidence in forest trees; it is equally obvious that through the use of good management practices they can be made more or less innocuous. Many diseases have erupted to epidemic proportions not because the pathogen has suddenly become more virulent, but rather because forest management, or mismanagement, has created an environment favorable to the pathogen. The real challenged, therefore, is to determine how to reverse this trend: how to establish a balance between trees and pathogens that will prevent catastrophic disease epidemics.

The possibility of preventing or controlling forest diseases through the action of organisms parasitic to or predaceous on pathogens has a strong appeal to the imagination but little basis in fact. There are many examples of fungi parasitic on forest pathogens and a few examples of insect predators, but there are no known instances of the reduction of a forest disease outbreak to tolerable levels through the action of such organisms. Conversely, there is ample evidence that parasites and predators of forest pathogens really thrive only when and after the pathogen is widespread and damaging. Under such circumstances they undoubtedly do reduce inoculum production but not sufficiently to suppress the epidemic. Most important of all, however, they failed to prevent the epidemic in the first place.

A few case histories illustrate the situation. There are several native fungi parasitic on the stem rusts of American conifers, of which the most widely distributed is the purple mold, *Tuberculina maxima*. When the white pine blister rust fungus was introduced into this continent about 60 years ago, this mold found it a more congenial host than any of our native rusts. In spite of this, it has been incapable of preventing the spread and intensification of blister rust throughout the range of the white pine species in the United States and Canada. Currently, there is evidence that it may be reducing damage from the rust on western white pine in the northern Rocky Mountain region but it most certainly has not controlled the disease there or elsewhere.

American beech in eastern Canada and northeastern United States has been severely damaged during the past 35 years by successive attacks of an introduced scale insect and a native but secondary fungus. After the pathogen is well established in the bark of trees previously infested by the insect, it in turn is commonly parasitized by a brown mold, *Gonatorhodiella highlei*, which eventually kills the pathogen, but not before it has spread to many more trees and, in most cases, has killed the tree on which it was established.

Dwarf mistletoes are parasitic flowering plants that attack, deform, and kill many western and northern conifers. There are numerous fungi parasitic on the dwarf mistletoes and several insects that feed on them, but in no instance is such action early and common enough to prevent further spread of the parasites. Artificial attempts to increase their effectiveness have failed to date.

In the case of *Fomes annosus* root rot of pines, particularly common and damaging in eastern and southern United States, the outlook for biological control is more promising. The action, however, will be through antagonism rather than parasitism. The causal fungus is native and widespread but is incapable of causing severe losses of naturally regenerated pines on undisturbed forest soil. On the other hand, it spreads rapidly and causes catastrophic losses in pine plantations on land previously under agricultural cultivation. It is thought that the use of land for the production of agricultural crops changes the soil flora and fauna and thereby eliminates those organisms that exert an antibiotic influence on the pathogen in forest soils. Research is underway to determine what microorganisms have been eliminated from forest soils by agricultural practices (cultivation, rotation, nutrient depletion, soil erosion, etc.), which of them are antagonistic to the root pathogen, and how to reintroduce them to land reverting to forest production. It is hoped that this may be accomplished by inoculation of nursery soil in which seedlings are grown before outplanting, thereby providing each seedling with its full complement of protective organisms.

In conclusion, there are tremendous opportunities to improve forest disease control by applying biotic measures of all kinds that favor tree growth or are detrimental to the spread and intensification of pathogens. In most cases, these will not be special measures over and above what is required for maximum tree growth, but they must be applied consistently and at appropriate times in the life of the forest to be fully effective. Biological disease control must be practiced from stand regeneration to maturity and harvest, must be preventive rather than palliative, and must be based on sound ecological concepts of the forest as a community of plants rather than as simply a stand of trees.